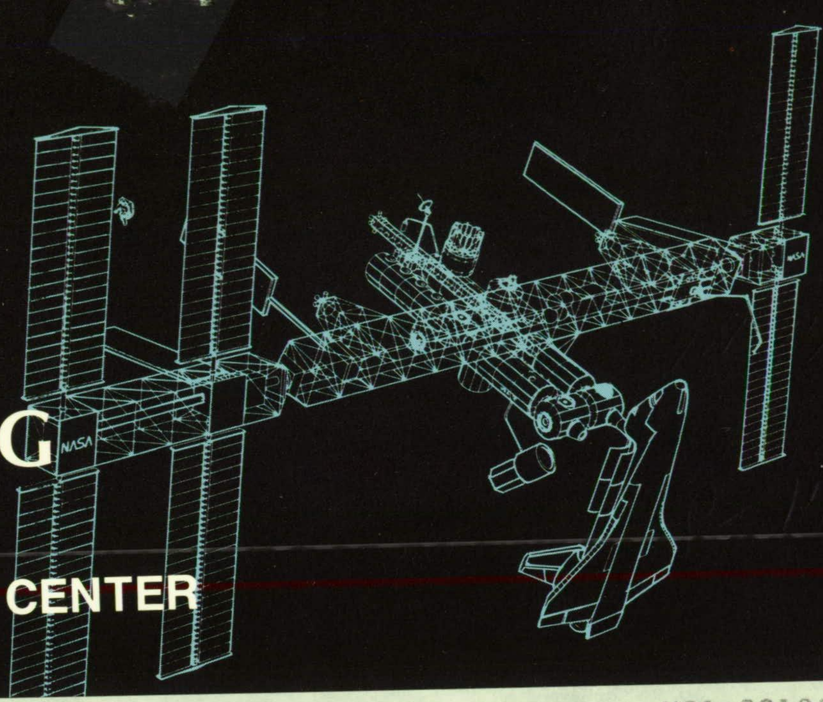
# POWER SYSTEMS TESTING

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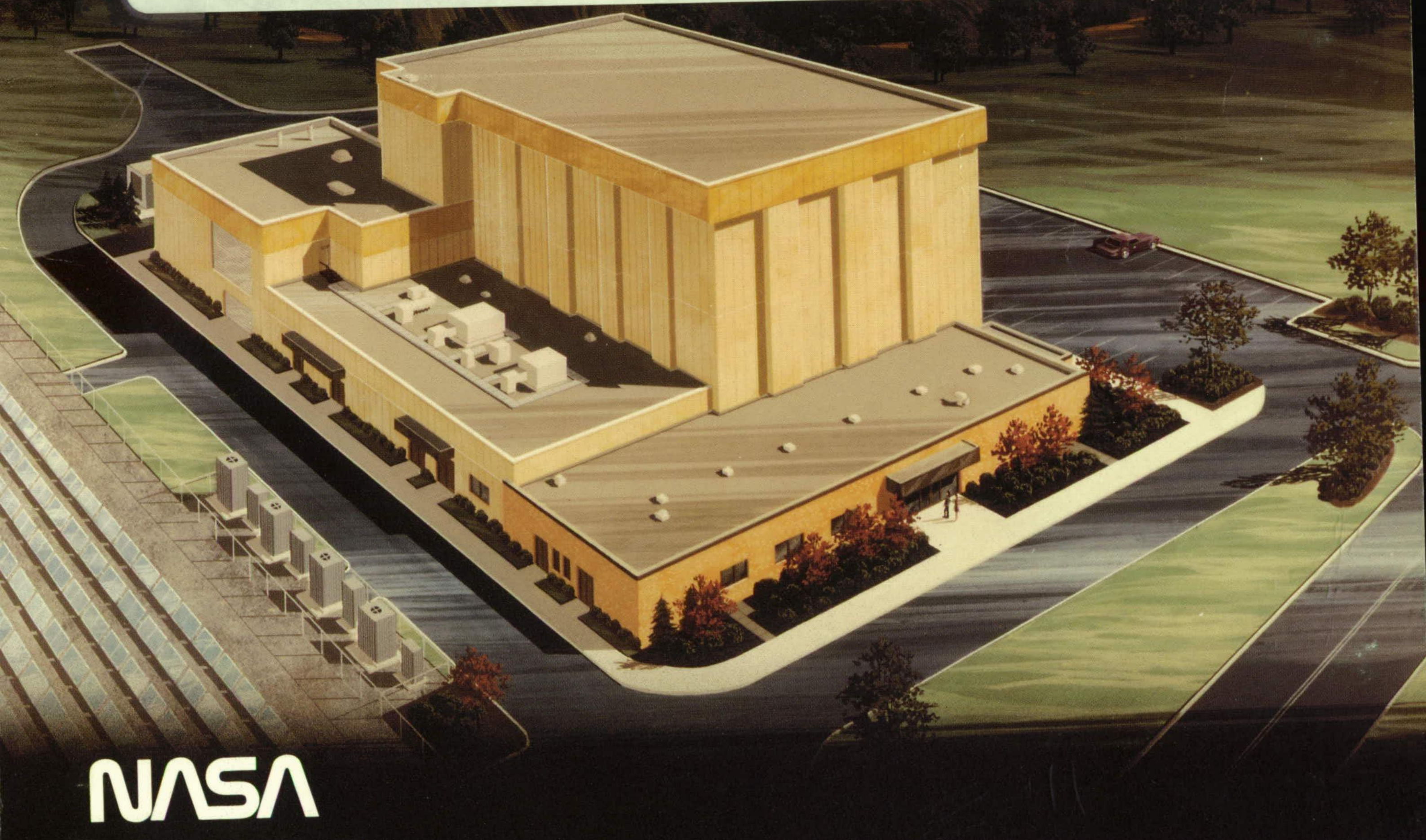

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# POWER SYSTEMS TESTING

## LEWIS RESEARCH CENTER

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Cleveland, Ohio

## Foreword

In 1984 President Ronald Regan directed NASA to undertake the development of Space Station Freedom, the next step in a broad-based U.S. civil space program to develop space-flight capabilities and exploit space for scientific, technological, and commercial purposes. Since 1985 NASA has been exploring design alternatives to accomplish this goal. The restructuring efforts of 1990-1991 have resulted in a finalized design of Freedom.

Here at Lewis Research Center, with our prime contractor, Rocketdyne, we are developing and building the electrical power system (EPS) hardware and software for Space Station Freedom. This power system will break new ground in the technology of high-power, automated space power systems.

Freedom will be the stepping stone into the future. We at Lewis are proud to provide crucial support to this effort.

Ronald L. Thomas

Ronald L. Thomas
Director
Space Station Freedom Directorate

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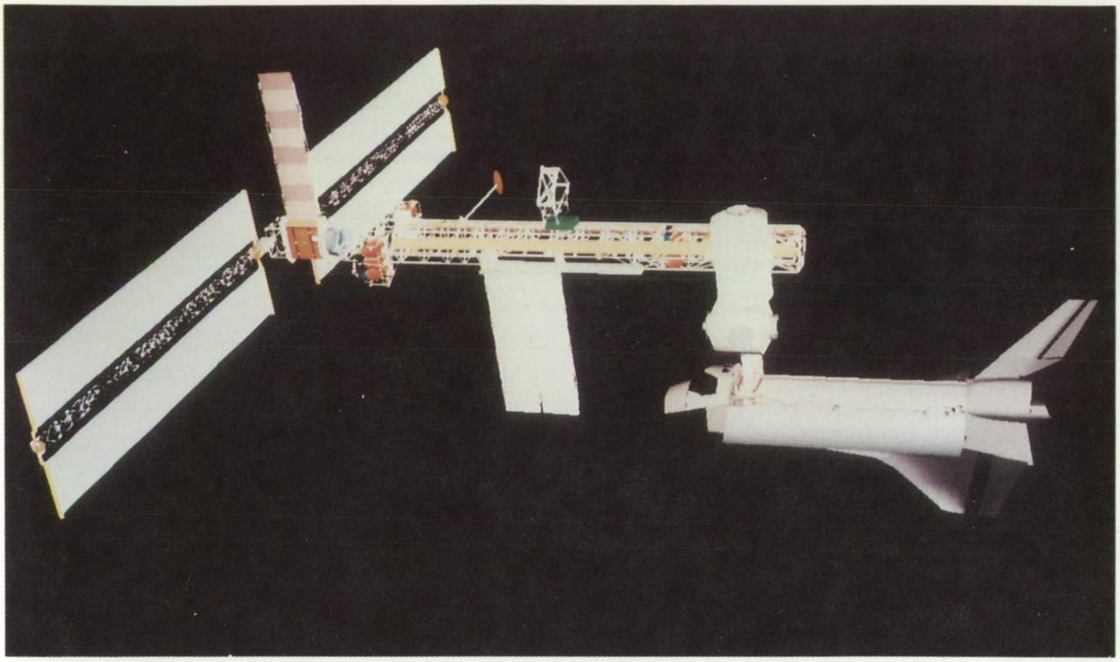

## Space Station Freedom–Man-Tended Configuration

Space Station Freedom will be constructed incrementally to ensure efficient use of the microgravity environment. By late 1996, construction will have progressed to the point where experimentation can begin in the laboratory module. Using a docked shuttle as living quarters, astronauts will continue to expand S.S. Freedom while performing experiments within Freedom's laboratory module. When a shuttle leaves, Freedom will operate unattended until the next shuttle arrives. During the man-tended configuration (MTC), Freedom provides 15 user experiment racks and 13 kilowatts of user-available power. Six shuttle flights will be required to construct the MTC.

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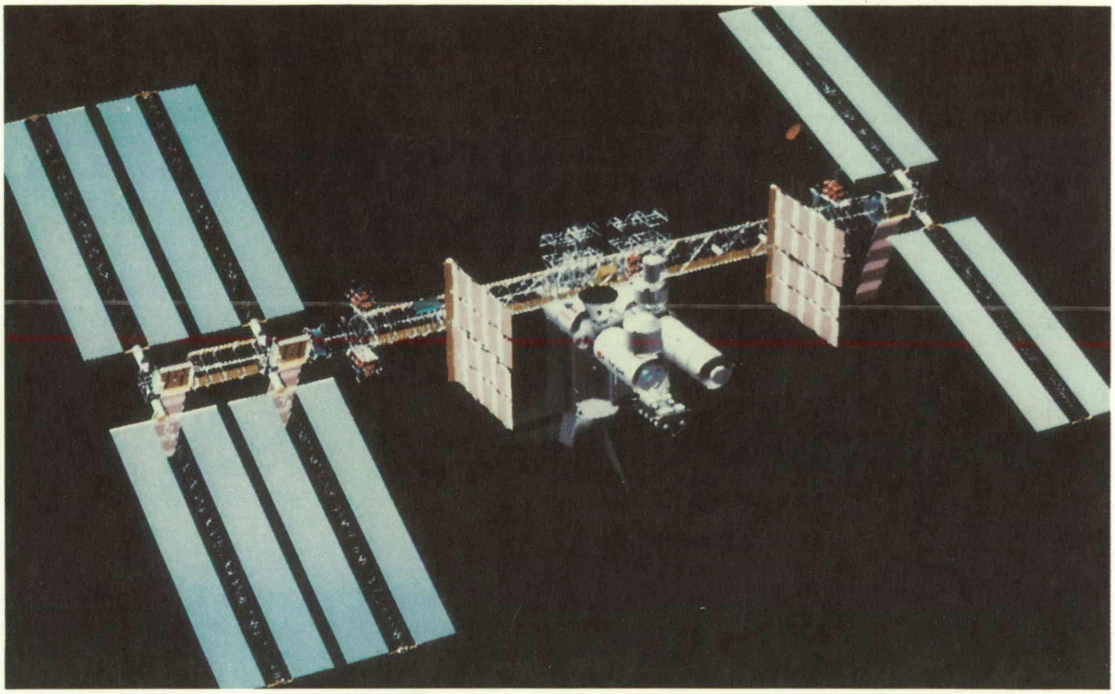


## Space Station Freedom–Permanently Manned Configuration

In the years following the completion of the MTC, approximately 16 shuttle flights will bring Freedom to its permanently manned configuration (PMC). In this configuration, three photovoltaic power modules will supply 30 kilowatts of power to the experimentors. Four astronauts will work in Freedom's laboratory module. Additional laboratory modules will be supplied by the European (ESA) and Japanese (NASDA) partners. The PMC will provide its users the ability to operate and observe long-term experiments on life sciences and materials/chemical research in a microgravity environment. With the addition of the NASDA exposed facility, an externally mounted payload capability will become available for use by the United States and our international partners.

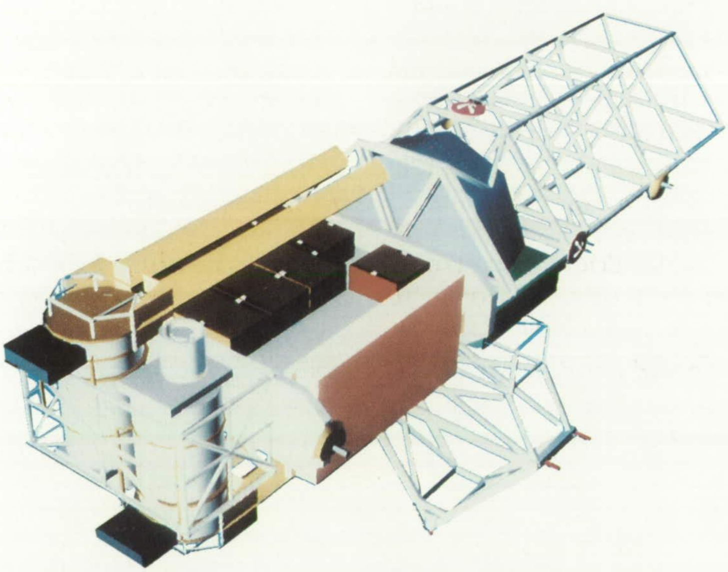
# Lewis Research Center's Role in the Space Station Freedom Program

The Space Station Freedom Program is managed (commonly referred to as Level I) by NASA Headquarters in Washington, D.C. Program direction (Level II) is centered in Reston, Virginia, with implementation delegated to various NASA centers (Level III). Along with Lewis, these centers include Marshall Space Flight Center and Johnson Space Center as hardware and software developers. The Kennedy Space Center provides ground operation support, and Langley Research Center supports technology development/evolutionary growth. In addition, the European Space Agency (ESA), Japan, and Canada are partners, each contributing hardware and software development to the Space Station Freedom Program.

Lewis Research Center has the responsibility for the S.S. Freedom electric power system (EPS). Rocketdyne, a division of Rockwell International, has been awarded the contract for the design, development, test, and evaluation of the EPS hardware and software.

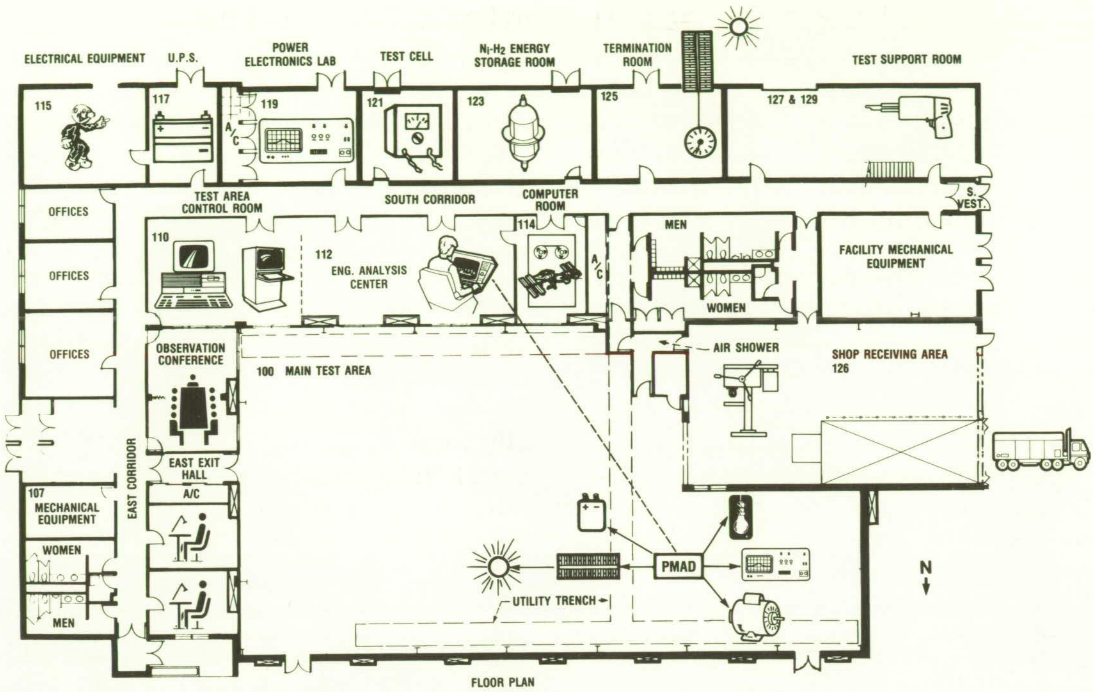
Power for Freedom will be generated by photovoltaic (solar cell) modules. Each module will consist of four photovoltaic blankets, a deployable mast system, batteries, and the associated power conditioning and control equipment. Each module will develop 18.75 kilowatts of usable power. Because of Freedom's low orbit (220 mi.), the electrical system is required to provide continuous power during the orbital eclipse periods. To provide this power, a system of nickel-hydrogen (Ni-$H_2$) batteries and their control electronics will give the continuous power necessary for the 30-minute orbital eclipse periods.

The power management and distribution (PMAD) system completes the Lewis electrical system. This computer-driven system automatically controls and distributes power to S.S. Freedom's systems and experiments.





Photovoltaic Launch Module




Utilization of the Power Systems Facility

## Power Systems Facility

The Power Systems Facility (PSF), dedicated in 1989, was constructed for the development and on-orbit operating support of the S.S. Freedom electrical power system. The PSF is Lewis' newest facility, built at a cost of $6.2 million; it provides for a wide range of electrical power component and system testing.

The PSF has several areas with unique features. These areas include—the main test area, the Ni-$H_2$ energy storage room, and the test cell. The main test area is an 8300-square-foot high bay area with a 55-foot clearance below the 10-ton crane. This test area can operate as a class 100,000 clean room that is capable of removing 90 percent of the airborne particles. The Ni-$H_2$ energy storage room and the test cell are explosionproof. They have interior walls and ceilings made of 12-inch reinforced concrete. Each room's exterior wall is designed as a blowout panel which will provide pressure release in the unlikely case of an explosion. These test cells are equipped with high-volume exhaust fans that are capable of completely changing the atmosphere in the cell in less than a minute.

The PSF utilizes an adjacent solar array field for power system and component testing. The solar array field consists of 960 silicon solar cell modules. The maximum array power is 30 kilowatts at 160 volts. The array field is tied to the facility through the termination room. The power produced by the array field is distributed from this room to other parts of the facility as required.

Hardware for the tests to be conducted in the PSF include Ni-$H_2$ batteries, solar concentrator mirror, and power management and distribution (PMAD) system and components. The PSF will include an engineering support center (ESC) to permit monitoring on-orbit power system performance. The ESC will have the capability of simulating any anomalies experienced in space for analysis and resolution.

**Utilization of the Power Systems Facility**

| Room | Room name | Utilization |
|---|---|---|
| 100 | Main test area | Contains the PMAD test bed, a two-channel model of S.S. Freedom's EPS. High bay area available for testing large spacecraft components. |
| 110 | Test area control room | Is the control room for the main test area, a secondary control room for other test cells, and a distribution center for control signals. |
| 112 | Engineering analysis center | Contains computers to permit analysis of the EPS performance during on-orbit operations of S.S. Freedom. |
| 114 | Computer room | Contains computers that simulate S.S. Freedom systems that interact with the power system being tested. |
| 117 | Uninterruptible power source (UPS) room | Contains an uninterruptible power source for clean, reliable power to the facility and the computers. |
| 119 | Power electronics laboratory | Contains equipment to accept, check, troubleshoot, and modify EPS components. |
| 121 | Test cell | Contains various equipment needed to test EPS components. |
| 123 | Ni-$H_2$ energy storage room | Permits life testing on Ni-$H_2$ batteries and battery packs. |
| 125 | Termination room | Interconnects the solar array power to the facility; solar array and battery simulators are also located here. |
| 126 | Shop/receiving | Serves as an unloading dock for delivered items and as a mechanical workshop; has the capability to become a pre-clean area for the main test area. |
| 127 and 129 | Test support room | Allows for the buildup of test support hardware. |
| 300 | Power systems automation laboratory | Contains computers to investigate automation concepts that increase productivity by simplifying the human involvement in power systems operation. |
| 400 | PMAD test-bed software support laboratory | Contains computers to develop the operating system and the network and control software for the PMAD test bed. Ada is the primary computer language used for this function. |

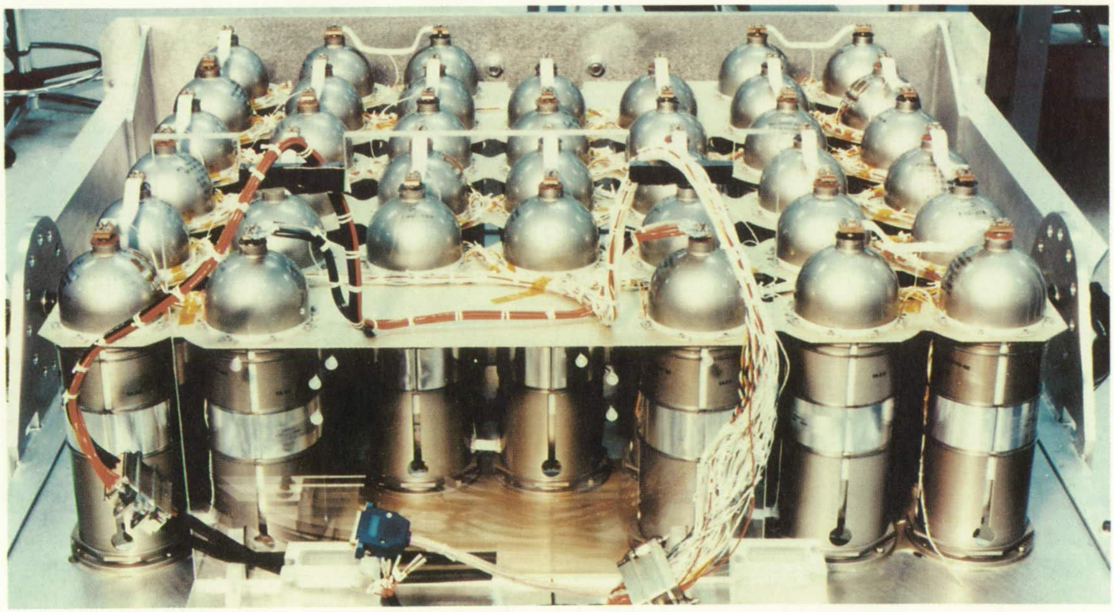
## Energy Storage Testing

Initial energy storage tests in PSF will focus on $Ni\text{-}H_2$ rechargeable battery orbital replacement units (ORU's) at the developmental level. Later, functional testing of two batteries (2 ORU's = 1 battery) operating simultaneously will be conducted.

The function of the battery ORU's in the EPS of S.S. Freedom is to store energy during the sunlight phase for use during the eclipse portion of the orbit. One battery ORU consists of 38 individual pressure vessel $Ni\text{-}H_2$ cells connected electrically in series. The battery ORU is capable of delivering 81 ampere-hours of stored energy at a minimum of 47.5 volts dc.

S.S. Freedom will be placed in a low Earth orbit of 220 nautical miles and will experience nearly 6000 sunlight/eclipse cycles per year. This quantity of cycles imposes severe environmental conditions which affect performance and life characteristics of the $Ni\text{-}H_2$ cells. Thus, this test program is being conducted to determine if the battery design will meet life and performance expectations.

In addition to life and performance data, this test program will provide information on various battery recharging methods, on-orbit operational scenarios, and handling procedures. The battery must interface with the battery charge/ discharge unit (BCDU) which controls battery function. Tests will be conducted which demonstrate proper battery-BCDU interaction and load sharing between two batteries.

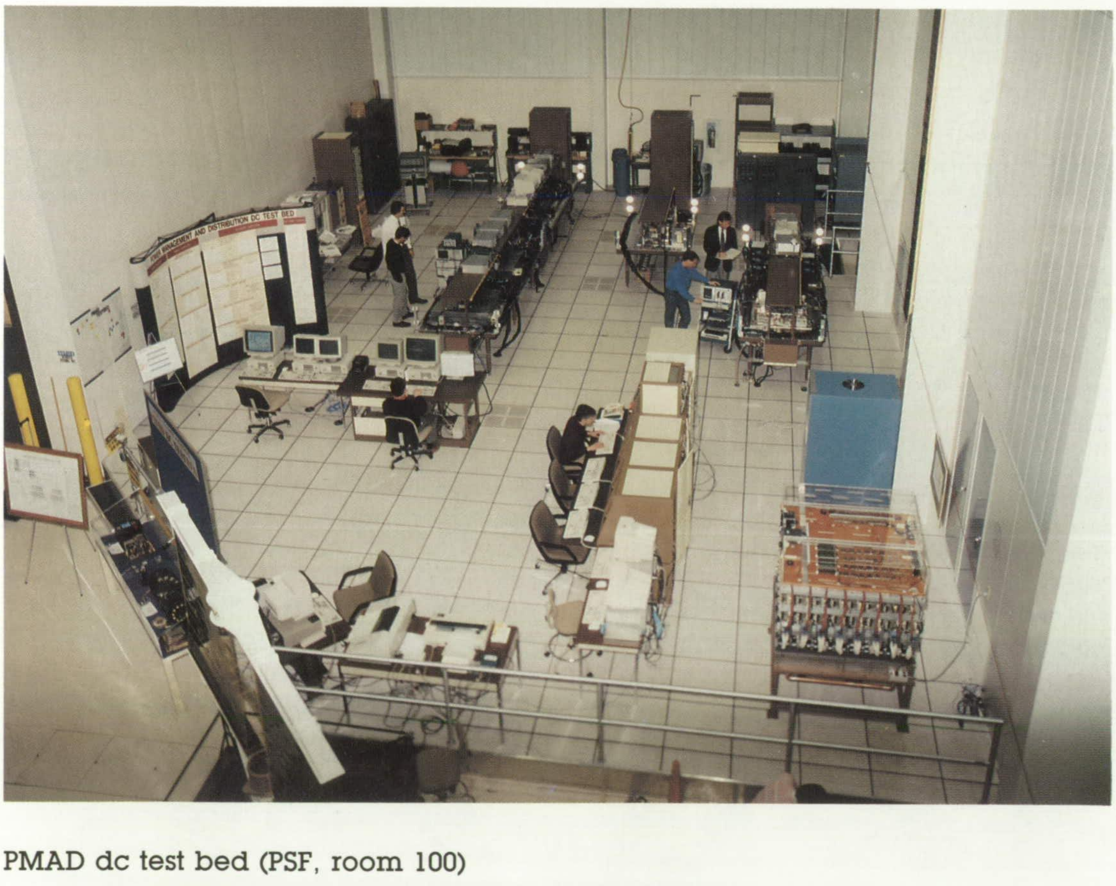


Engineering Model SSF Battery ORU

## Power Management and Distribution System Testing

The power management and distribution (PMAD) system distributes the electrical power from the solar arrays to the user (electrical wall outlets). The system consists of cables, power processing units, and switchgear—all coordinated by a distributed microcomputer control system. All these components are partitioned into several separate power channels to provide system redundancy. As the station grows, these channels can be parallelled to provide power to larger loads.

The facility currently houses a test bed that is an early miniversion of S.S. Freedom's power system. This test bed supports the continued development, testing, and refinement of the EPS design. Eventually the facility will house another test article which will verify the operation of the end-to-end EPS from the source to the user loads. Included in this verification will be the testing of system performance, power quality, system fault control, communications with astronauts, and ground control.



PMAD dc test bed (PSF, room 100)

## Importance of System Testing to the S.S. Freedom Program

System validation will be performed in both NASA Lewis and contractor facilities to insure that the EPS performs its proper functions and operates in a manner that is safe for the space station crew. The combination of environmental testing of PMAD components together with the full-system functionality tests at the PSF will insure that a fully operational EPS is qualified for Space Station Freedom.

## Test Beds in PSF

PSF houses specialized test beds for PMAD system testing. The test beds support the full power tests by verifying critical system concepts, testing hardware during the early stages of development, and identifying and resolving areas of concern in testing prior to the end-to-end system verification. The current test bed activity includes three key installations, the PMAD dc test bed, the test bed software support laboratory, and a power electronics laboratory.

The PMAD dc test bed emulates all the functions of the flight power system from the PV array and battery sources through the user loads. It contains functionally equivalent hardware components and assemblies integrated into a power channel that replicates a power channel on S.S. Freedom. It also uses an actual solar array or an array simulator, battery simulators, and simulations of representative user loads. The PMAD dc test bed differs from the proposed flight end-to-end configuration in that early development hardware is used until higher fidelity components become available. The PMAD dc test bed is useful in evaluating system level design issues and operating concepts in a realistic environment early in the program. It also provides a platform to evaluate actual user load compatibility and operational constraints.

The test bed software support lab is the development facility for the controls for the PMAD dc test bed. Software development is accomplished using the Ada programming environment. The Ada software is initially checked in the test bed support lab and then exercised in the PMAD dc test bed for verification. The test bed support lab provides early prototyping of test bed control algorithms implemented in the Ada programming language.

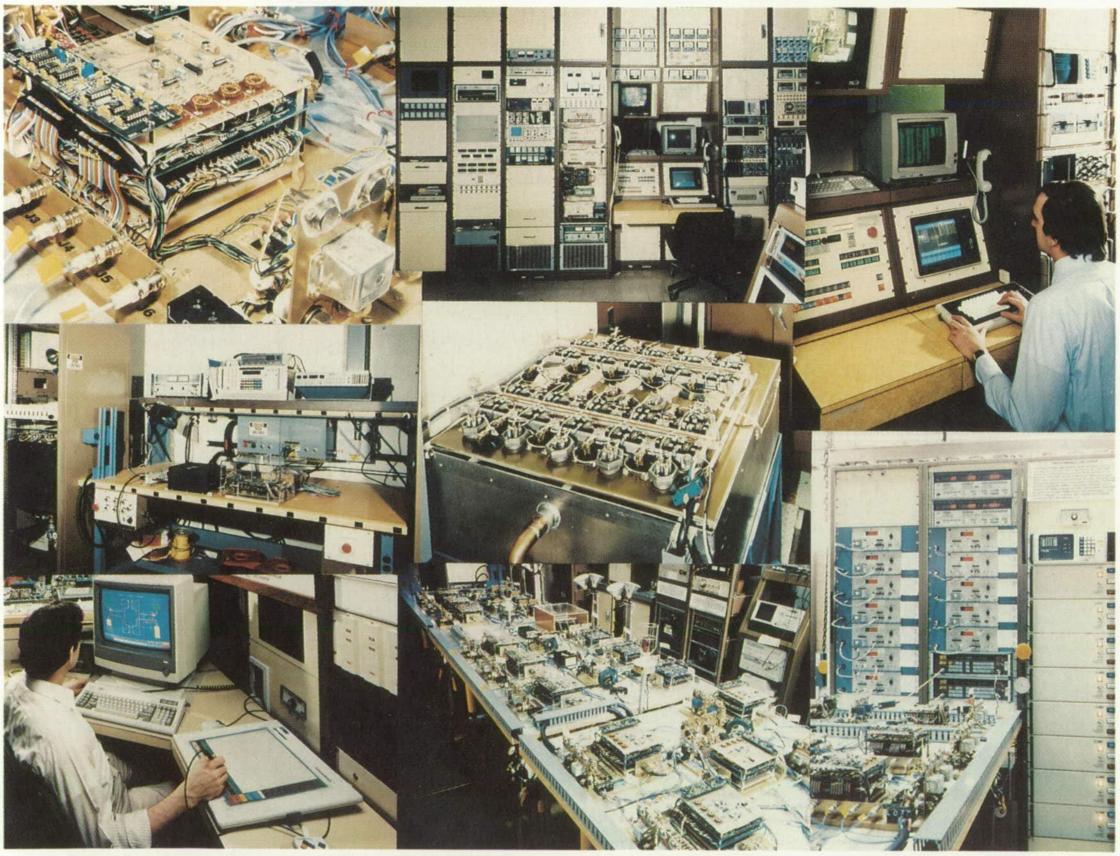
The power electronics lab supports the testing of individual components prior to integrating them into the PMAD dc test bed. The performance of the components can be measured, and the software and controls functions can be verified without interfering with the system testing functions of the PMAD dc test bed.

## Role of PSF in System Testing

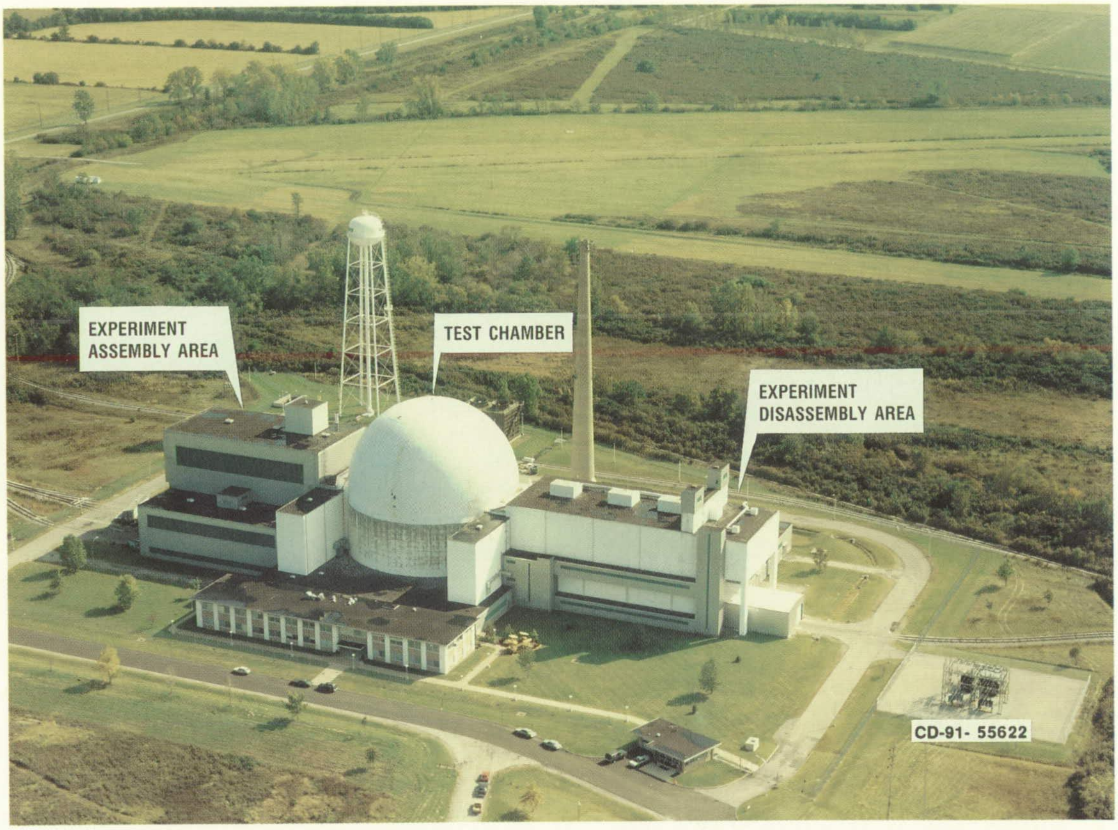
The PSF plays a key role in component and systems testing to ensure that the components and assemblies will operate together as a system on-orbit. The electrical system integrated tests (ESIT) will be performed using a combination of engineering model hardware, flight software, and high-fidelity simulators. The PSF is particularly suited to this type of testing because of its capability for testing a complete system including full-sized hardware, simulated or real power sources and loads, and distributed controls.

S.S. Freedom will be launched in segments because of its size. After each launch, the EPS will have a new configuration closer to the complete configuration. ESIT will verify that each of these intermediate configurations and the final one perform as expected.

As S.S. Freedom grows, the end-to-end test configuration in the PSF will be expanded by adding additional PMAD hardware and software. All new functions and additional interfaces will be tested.

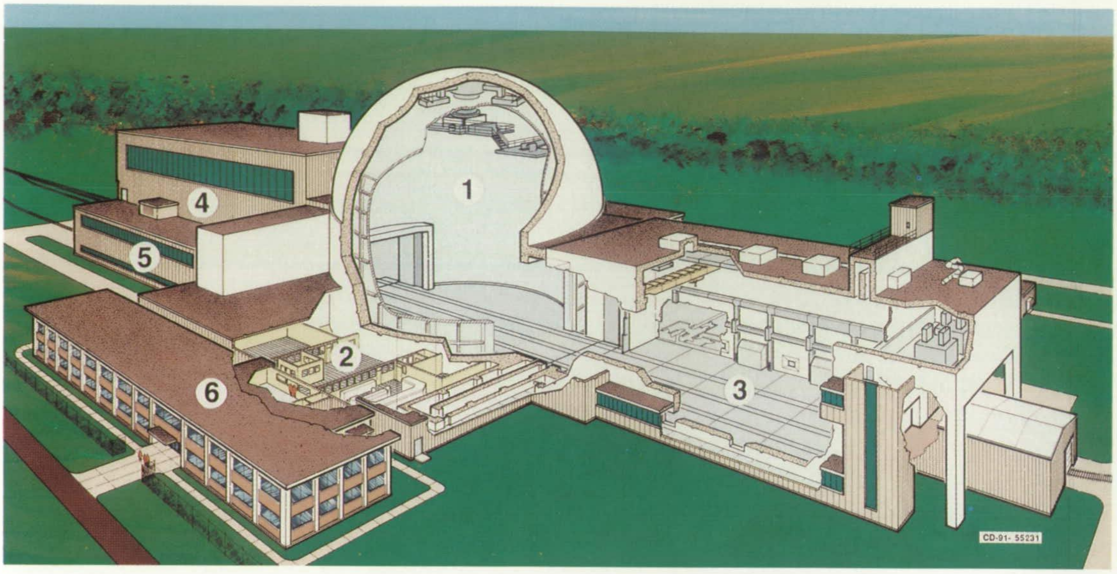


Electric power system testing




## Plum Brook Space Power Facility

The Plum Brook Station is a field station of the Lewis Research Center. It is located 46 miles west of Lewis near Sandusky, Ohio. The Space Power Facility (SPF) is one of several unique test facilities at Plum Brook. An existing facility built in the 1960's, it contains the largest vacuum chamber in the world. SPF was designed to simulate a space environment over a wide range of thermal and vacuum conditions for testing advanced propulsion and space power systems.

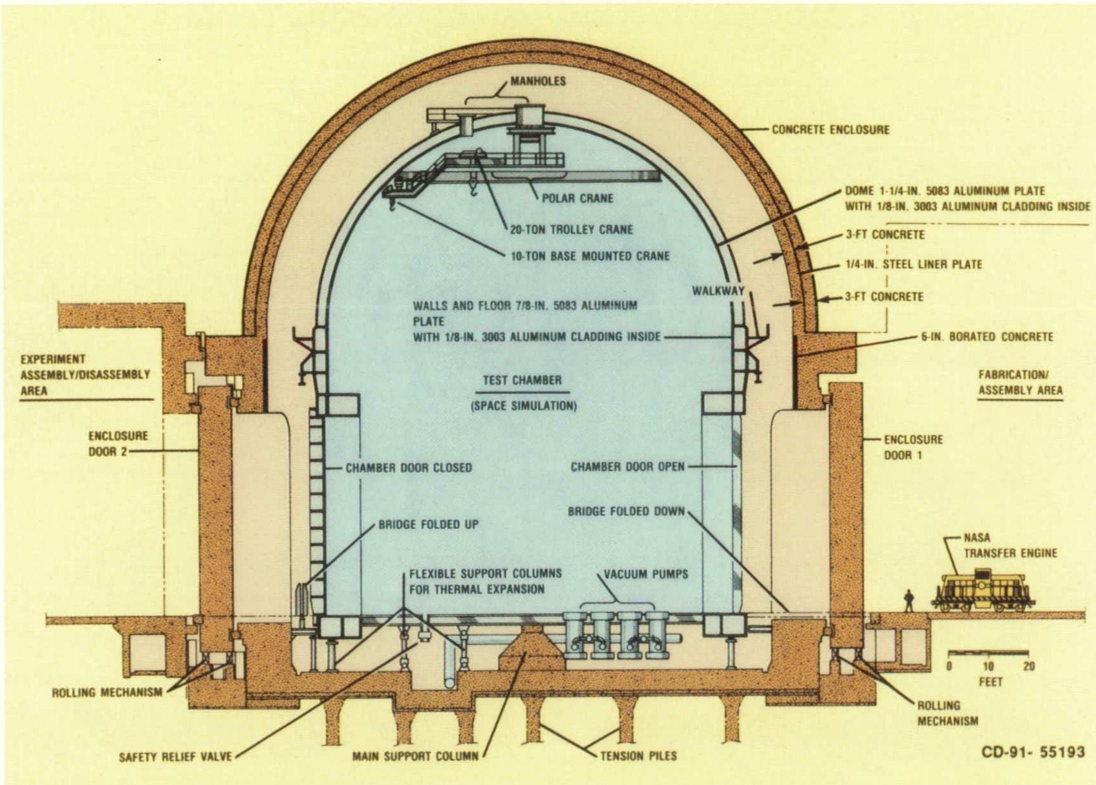



## Space Power Facility

**(Artist's Conception with Cutaway Views)**

Important architectural features of this facility include the following:

1 Empty chamber with its outer concrete and inner aluminum walls and its 50-foot by 50-foot doors.
2 Control rooms. Included are the facility control room (828 sq ft) and the test control and data acquisition area (2556 sq ft).
3 Large experiment assembly/disassembly area (150 ft by 70 ft by 76 ft high). Note the three railroad tracks on the floor for mounting and moving test hardware and the 20-ton bridge crane overhead. This area and the chamber are surrounded with concrete walls 6 feet thick. This feature of the original design provides nuclear shielding when required. Also, this area is coated with epoxy paint and is capable of being converted into a clean room.
4 Fabrication/assembly area (150 ft by 75 ft by 76 ft high). It has a 25-ton bridge crane.
5 Shop area (150 ft by 50 ft by 40 ft high). It has a 10-ton overhead crane along with machine tools and sheet metal fabrication equipment.
6 Forty-five offices (each being 279 sq ft).




SPF is the world's largest vacuum chamber, having a 100-foot diameter and a 122-foot height. This large volume facilitates testing a complete spacecraft, a two-stage medium weight rocket, or upper atmosphere phenomena. In addition to its unique size, SPF provides the following outstanding facility and test support equipment capabilities:

- An altitude capability which ranges from sea level to the low Earth orbit altitude of about 150 miles
- A cryogenic system capable of providing temperatures to −300 °F to simulate the coldness of space
- A 7-megawatt dynamic radiant heater using quartz lamps to simulate the Sun's heat
- A 400-kilowatt arc lamp for solar light simulation

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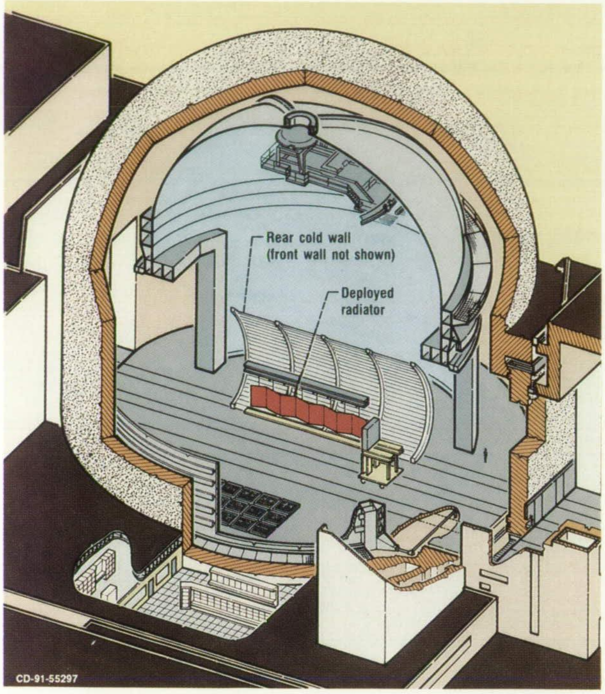
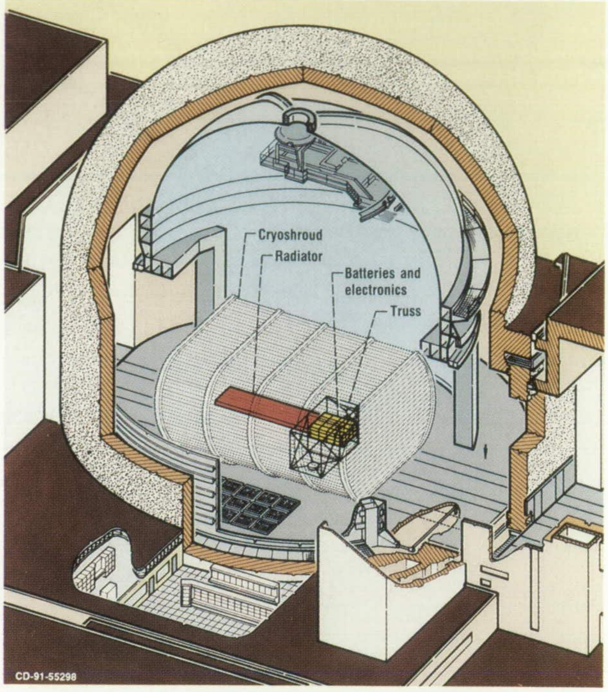
## Planned Space Station Freedom Tests




### Radiator Deployment Test

When the shuttle delivers the photovoltaic module to S.S. Freedom, the module's radiator is folded to fit into the shuttle. This test will repeatedly unfold and extend the radiator from its stowed position into its orbital operating position and then fold it up again. Before and during deployment the radiator will be exposed to the vacuum and thermal environment of low Earth orbit. To provide the cold temperatures of space, the walls shown will be cooled with chilled gaseous nitrogen. Quartz lamp heaters will provide the warmth of the Sun on one side. The test will verify that the deployment mechanism can operate under thermal stress (one side hot, the other side cold) in the vacuum of space.

### Integrated Photovoltaic Module Test

The integrated photovoltaic module consists of all the equipment which processes the power from the solar arrays to make it usable for S.S. Freedom. (The solar arrays themselves will not be included in this test and are not shown.) Critical assemblies to be tested include the batteries, radiator, and power conversion electronics. Quartz lamps will simulate the Sun's heat, producing temperatures to 235 °F on the module. The nitrogen-cooled cryoshroud will simulate the cold of space, producing temperatures to − 185 °F on the module. Integrated operation of all the components and systems—electrical, thermal, and mechanical—will be verified in a simulated space environment.

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# Report Documentation Page

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15. Supplementary Notes

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16. Abstract

Space Station Freedom (SSF) will give the United States a permanent manned presence in space in 1999. The SSF underwent its final design concept in 1991. Launches of hardware will begin in late 1995, and the SSF will become operational in the man tended configuration in 1997. Additional shuttle flights between 1997 and 1999 will complete the SSF. Along with international partners, a crew of four astronauts will conduct long-term experimentation in the microgravity environment of the orbiting spacecraft. Lewis Research Center, along with its prime contractor Rocketdyne Division of Rockwell International, will provide the electrical power system (EPS) for SSF. Two major testing facilities at the Lewis Research Center will support the Lewis EPS. The Power Systems Facility provides test beds for life testing the station batteries and the power management distribution system testbed. This testbed simulates two channels of the EPS. The Space Power Facility at the Lewis Plum Brook Station is the largest vacuum chamber in the world. Within this chamber, a simulated space environment, testing of full-size EPS components will occur.

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